NOTE ON MOUNTAIN-TOP MEASUREMENTS OF ATMOSPHERIC ELECTRICITY IN NORTHWESTERN UNITED STATES

W. E. COBB, B. B. PHILLIPS, AND P. A. ALLEE

Atmospheric Physics and Chemistry Laboratory, ESSA, Boulder, Colo.

ABSTRACT

Atmospheric electric measurements were made during the summer of 1958 from the summit of Mt. Washburn in Yellowstone Park, Wyoming. These measurements included the electric field, the positive and negative electrical conductivities, the charge on individual raindrops, the size and charge of individual cloud droplets, and the corona discharge current from the earth's surface associated with high electric fields beneath thunderstorms. Electric fields exceeding 600 v.cm.$^{-1}$ were recorded. Specific results are presented and interpretations made of their significance.

1. INTRODUCTION AND PURPOSE

During the summer of 1958 a series of atmospheric electrical measurements were conducted from a mountain peak in Yellowstone Park, Wyo. The results of these measurements were reported at the Washington meeting of the American Meteorological Society in May 1959. It is felt that the measurement results are of sufficient interest that they warrant publication.

2. LOCATION

Mt. Washburn, located in Yellowstone National Park, was chosen as the site to conduct the measurements. Situated in the northern United States Rockies, the region is relatively free of pollution sources. Mt. Washburn is an isolated prominence rising 10,317 ft. above sea level. The surrounding terrain approximates 7,500 ft. m.s.l. To the southwest the land falls away gradually along the Snake River Valley decreasing in elevation to 5,000 ft. m.s.l. at a distance of 200 mi. In other directions, Mt. Washburn is ringed by terrain of equal or greater height at a distance approximating or greater than 30 mi. The prevailing winds during the summer flow from the southwesterly direction from the Snake Valley. Orographic lifting of the air occurs regularly, resulting in extensive cumuliform cloud development in the Yellowstone area. The mountain peak is accessible by road from about June 15 until early October. Through the courtesy of the National Park Service space was made available for use within the second floor of a fire lookout tower at the summit.

3. MEASUREMENTS

The measured data reported here included the electric field, the positive and negative electrical conductivities, the charge on individual raindrops, and the corona discharge current occurring from a given surface during periods of high electric fields occurring with and beneath thunderstorms. Measurements of the size and charge of individual cloud droplets and the rate of production of light ions were also made but are not reported. The normal meteorological observations of wind, temperature, etc. were not made on a routine basis.

4. INSTRUMENTS

The electric field was measured by a rotating inductor-type field meter (Gunn [4]). The inductor element was placed in an artificial ground plane 6 ft. square and 15 in. above the normal surface of the mountain. This assemblage was positioned a distance of twice the height of the lookout tower from the tower base. A calibration determined that the recorded electric field values measured by this system were greater than indicated by a nearby radioactive probe by a factor of 3/2. This increase occurs because of the raised position of the artificial ground surface surrounding the rotating inductor. The electric field values throughout this report are those actually recorded from the rotating inductor field meter as described.

The positive and negative electrical conductivities were measured by means of two similar Gerdien conductivity apparatus, described previously by Allee and Phillips [1].

The collection currents from the central collectors passed to amplifiers and allowed continuous recording of the simultaneous values of positive and negative conductivity.

The charge on raindrops was measured using an apparatus similar to that described by Gunn [3]. The method consisted of capturing the freely falling drops in a Faraday cage. The resulting electrical signal was amplified and fed to a viscous damped recording galvanometer having a flat response to 1500 hertz.

Corona discharge currents were measured from a 2.15 m.² sod surface which was transplanted from a nearby mountain location to an insulated tray mounted adjacent to and at the same height as the ground plane surrounding the electric field meter. The sod, which was representative of the mountain surface in the surrounding area, was principally grass 10 to 15 cm. in height but contained a few mountain flora of height 20–25 cm. A low resistance galvanometer connected between earth and the insulated tray gave a continuous record of the corona discharge current from the grass surface.

All data from the separate instruments were recorded on a multi-channel oscillograph.

5. FAIR WEATHER MEASUREMENTS

Measurements were made during the period from July 14 to August 18, 1958. Approximately 120 hr. of data were collected during fair weather. A typical record obtained under fair-weather conditions is reproduced in figure 1a.

The true fair-weather electric field at the site approximated −3 v./cm. (corrected). Normal variations of 10 percent above and below this figure occurred frequently. Clark [2] has reported the fair-weather electric field normal to this altitude as obtained from the aircraft measurements approximates 30 v./m. It appears, therefore, that the field at the observation point is enhanced by a factor approximating 10 due to the topography of the mountain surface.

For purposes of establishing mean conductivity values in fair weather, the following limitations were set. First, conductivity was averaged only during periods of good visibility with no precipitation within the vicinity of the summit. Second, values were utilized only during periods wherein the electric field remained between −1 and −7 v./cm. With these restrictions the computed mean values were determined:

$$\lambda_+ = 3.25 \times 10^{-4} \text{ e.s.u.}$$

$$\lambda_- = 2.85 \times 10^{-4} \text{ e.s.u.}$$

The total conductivity ($\lambda_+ + \lambda_-$) averaged 6.1×10^{-4} e.s.u., and varied widely from approximately 2.0×10^{-4} to 12.0×10^{-4} e.s.u. The ratio of the mean conductivities λ_+/λ_- is seen to be 1.14. Normal variations in the ratio of measured conductivities were observed to be within the limits 0.7 to 2.0. Again the total variation occurred between the ratios 0.9 to 1.5 throughout 84 percent of the recording period. Figure 2 is a plot of the variation of the

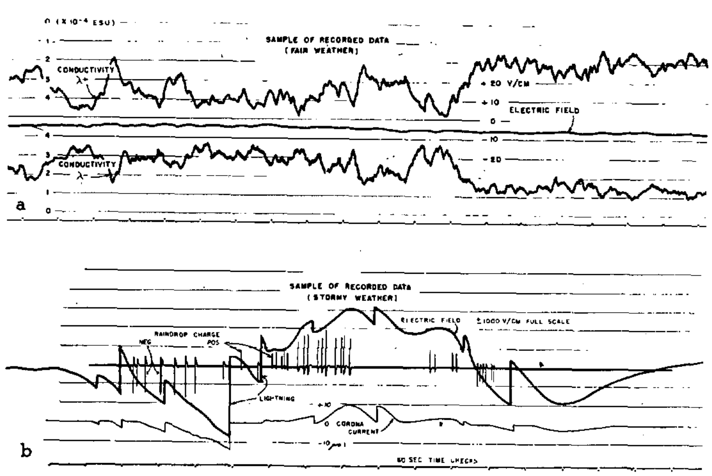

FIGURE 1.—Sample of recorded atmospheric electric data from mountain peak in Yellowstone Park during (a) fair weather, (b) stormy weather. Conductivity and electric field were recorded in fair weather; during thunderstorms additional measurements were made of the charge on individual raindrops and the corona current emitted from a 2.15-m.² grass plot.

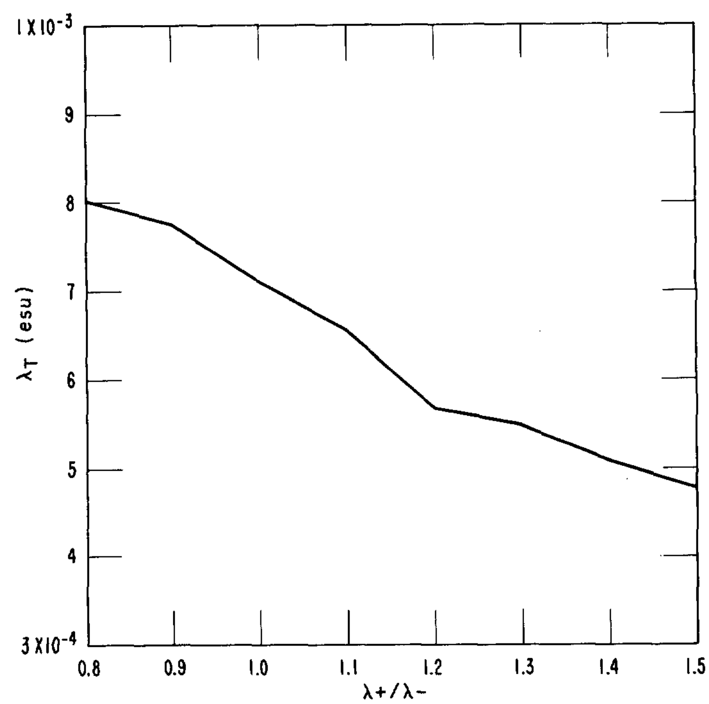

FIGURE 2.—Total conductivity versus the ratio of the polar conductivities. An increase in the ratio of the positive to the negative conductivity, together with a decrease in the total conductivity, indicates an increase in the atmospheric fine-particle pollution.

conductivity ratio versus total conductivity obtained during the fair-weather period. This shows clearly an increase in the total conductivity accompanying a decrease in the conductivity ratio.

6. STORMY WEATHER DATA

Data were recorded during 27 storms which passed over or near Mt. Washburn. Of these 27 storms, 13 were accompanied by precipitation at the station, six produced hail, and all displayed virga. A typical record obtained during stormy weather is shown in figure 1b. An attempt was made to analyze the different storms into groups as regards their individual characteristics, the frequency of occurrence of lightning, general intensity of the electric field, duration of the storm, etc. Due to the random nature of each individual storm character this method of grouping was not feasible.

ELECTRIC FIELD

No systematic electric field was apparent during thunderstorm development or passage. Recorded field strengths of 500 to 600 v./cm. were common and on one occasion the measured field exceeded 1000 v./cm. Lightning struck the lookout tower on two occasions, each time disrupting the measuring program. The electric field was measured at the moment of lightning discharge on only one of these strikes at which time the field approximated 400 v./cm. In general the periods of positive electric field and the positive field strength maximums exceeded the negative counterpart.

CONDUCTIVITY MEASUREMENTS

During periods of moderate electric fields the electrode effect became the controlling factor in all conductivity measurements. This effect leads to a deficiency of the positive or negative ion depending upon the sign of the field as discussed in atmospheric electric literature. At high electric fields the conductivities are strongly influenced by a large corona discharge from the mountain surface. The conductivity measurements appear to have little significance under these conditions and will be disregarded as a purely surface phenomenon.

RAINDROP CHARGE

Figure 3 shows the distribution of raindrop charge with electric field occurring at the time of the droplet capture. The numbers plotted are the number of droplets observed to carry the charge, Q, given by the abscissa at the time when the electric field was that given by the ordinate. The sign of charge generally agreed with the sign of the electric field. Included in these data are all charged hail and graupel which fell with rain. A separate plot originally made of the hail and graupel charge showed no apparent variation between the overall charge distribution of the frozen hydrometeors and rain.

CORONA DISCHARGE CURRENT

Figure 4 shows the variation of the corona discharge current from the sod surface with the measured electric field. The data taken during any particular storm closely followed a curve like those shown in the figure. Storms on different days, however, showed a different relationship between the field and the corona current. The observed result then was a family of curves for successive days. The extreme values are shown in figure 4 along with median current versus electric field (the curve for July 31). On other days the discharge current followed curves lying between the two extremes as indicated by the curve for July 31.

7. DISCUSSION

FAIR WEATHER DATA

In general, it was observed that the ratio λ_+/λ_- decreased in cleaner air. For example, a cold front passage or an extended period of rainy weather were followed by high values of negative conductivity relative to the positive conductivity.

This decrease in the conductivity ratio can be explained in terms of the nuclei density of the ambient air. In rela-

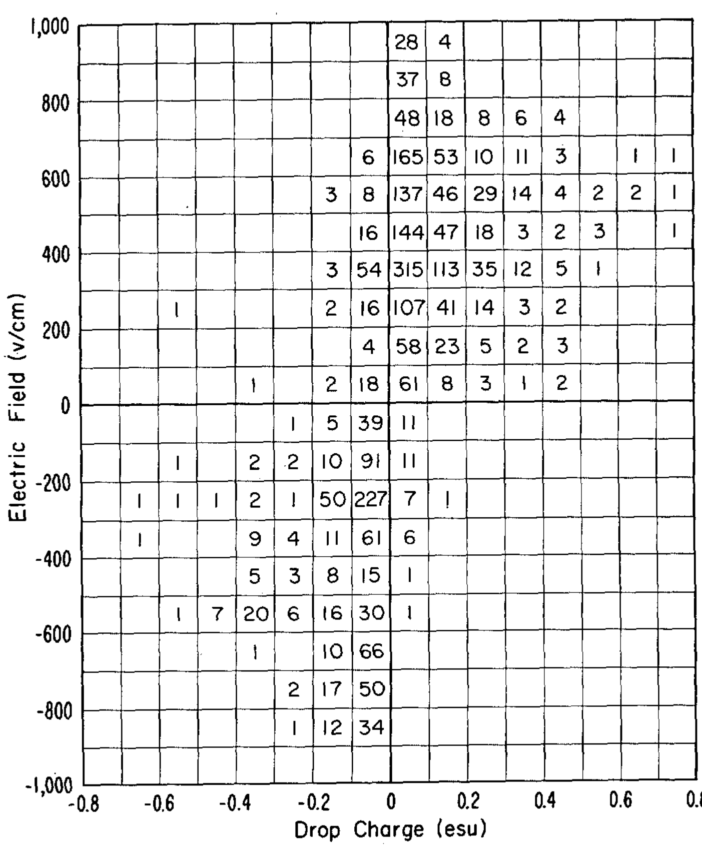

FIGURE 3.—The distribution of raindrop charge with the electric field that occurred when drop was captured. The grid figures are the number of drops carrying the charge given by the abscissa, when the field is that given by the ordinate.

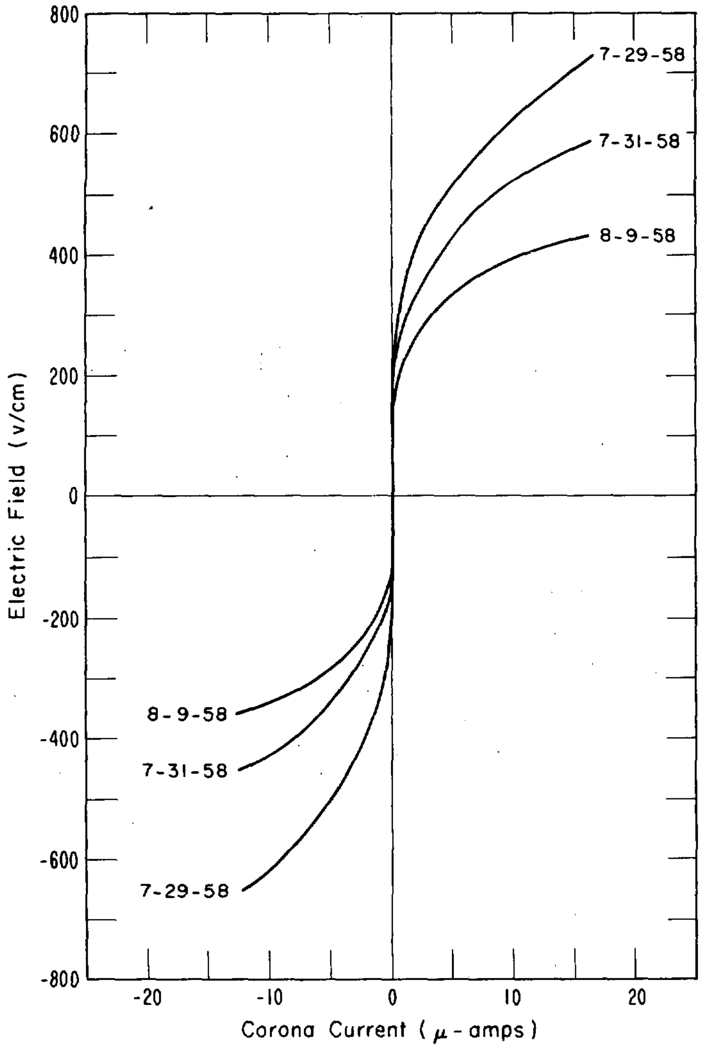

FIGURE 4.—Corona discharge current occurring from a 2.15-m.[2] grass surface during high electric fields.

tively clean air, few ions are immobilized by attachment to "massive" particulate matter because of the few particles. The respective ion concentrations are, therefore, determined by the rate of ion formation and small ion recombination. Since ions are always formed in pairs, the ratio of conductivities approaches the ratio of the respective ionic mobilities, $u_+/u_-=0.73$ (Loeb [7]). As pollution within an air mass increases, a greater number of ions are captured by airborne particulate matter and because of their low mobility these ions cannot enter into the normal conductivity current. It has been shown that negative ion loss to the immobile particles is more rapid by the diffusion mechanism than is the positive ion loss (see Gunn [5]) so there is a relative increase in the value of the positive conductivity with respect to the negative conductivity with increasing nuclei density. In turn, the total conductivity will increase in the absence of foreign particulate matter because of the greater small ion density. These effects are seen in figure 2.

It was noted during the course of the measurements that sharp discontinuities occurred in the average values of the positive and negative conductivities concurrently. For example, on one occasion the polar conductivities jumped from a stable level of approximately 2×10^{-4} e.s.u. to a level of 4×10^{-4} e.s.u. These sharp discontinuities were apparently attributable to the vertical convection of clean air from above to the observation site.

From 40 to 50 hr. of fair-weather data were taken at night. The total conductivity during this time was slightly higher than the average overall fair-weather conductivity. Again the increase was probably due to the influx of cleaner air. On most nights there was pronounced drainage of air down the slopes of the mountain so presumably the air at the summit was continually being replaced by a flow of air from above.

The observed values of the fair-weather conductivity and electric field indicate that the fair-weather conduction current over mountain surfaces is, as would be expected, several times greater than that which occurs over most of the land and sea surfaces of the earth. The calculated fair-weather conduction current based upon the actual mean observed electric conductivity and the corrected fair-weather electric field at our site is approximately 60 times the normal sea level conduction current. Such an estimation shows the pronounced influence on the worldwide atmospheric electric variables by mountainous areas.

MEASUREMENTS ASSOCIATED WITH THUNDERSTORM ACTIVITY

The corona current measurements made beneath thunderstorms were not initiated until the last half of the data collection program and as a result do not include the currents measured during the highest electric fields observed. The general character of the curves however is quite clear and can be extended at least as far as the highest observed electric fields without probable error. From these data it is seen that the corona currents from the mountain surfaces often approach 5 a./km.^{2} and may under the highest electric field become 2 or 3 times this value. Beneath the average thunderstorm where the effect of a given charge center may be spread over several square kilometers, the total corona current is large. In comparison, active thunderstorms discharge at the rate of once every 10 sec. and average something like 20 coulombs per discharge from which it is seen that the charge separation current in an active storm approximates 2 a. Raindrop data, which show positive correlation between the charge carried to the earth and the sign of the electric field, carry a portion of this charge again to earth. Without a record of rainfall intensity versus charge no estimation can be made of the amount of charge returned by the falling raindrops. Since much of the developed precipitate of the clouds over the Yellowstone area during the summer months occurs as virga and in general rain intensities are small, it is believed that the returned current carried by the falling drops is not comparable to the discharge current from the earth's surface under high electric field conditions.

The curves for corona current versus electric field showed a generally increasing slope during the measurement period. This was probably associated with a gradual drying of the sod transplant and perhaps to an increasing height of the plant growth. The sod was watered periodically but general drying throughout August was evident.

The raindrop and hail particle charge dependence on the electric field at the summit is believed to be the result of conduction charge transfer within the lower few hundred meters for fall. The conductivity apparatus and the corona current measurement show that the existence of fields common to thunderstorm passage created unipolar ion concentrations of large magnitude at the station. Under such conditions the falling polarized drop will rapidly acquire charge of that sign ion rising from point discharge from the mountain surface. For electric fields strong enough to cause active corona the ion concentration above the surface would be very great. The vertical extent of the charging region was probably not more than a few hundred meters as evidenced by the continued high electric fields with active corona. The passage of storms was inevitably associated with high winds which acted to carry the region of high ionic space charge away.

Figure 1b shows the alteration of drop charge which occurs with field reversal. The strong dependence between charge and field appears in contradiction to the results of Gunn and Devin [6]. The two data are not comparable however. The Gunn and Devin measurements were obtained over generally level, low terrain where electric fields were commonly 100 v./cm. or less and where appreciable point discharge currents were not established.

REFERENCES

1. P. A. Allee and B. B. Phillips, "Measurements of Cloud Droplet Charge, Electric Field, and Polar Conductivities in Supercooled Cloud," *Journal of Meteorology*, vol. 16, No. 4, Aug. 1959, pp. 405–410.
2. J. F. Clark, "Airborne Measurement of Atmospheric Potential Gradient," *Journal of Geophysical Research*, vol. 62, No. 4, Dec. 1957, pp. 617–628.
3. R. Gunn, "Electronic Apparatus for the Determination of the Physical Properties of Freely Falling Raindrops," *Review of Scientific Instruments*, vol. 20, No. 4, Apr. 1949, pp. 291–296.
4. R. Gunn, "Electric Field Meters," *Review of Scientific Instruments*, vol. 25, No. 5, May 1954, pp. 432–437.
5. R. Gunn, "The Statistical Electrification of Aerosols by Ionic Diffusion," *Journal of Colloid Science*, vol. 10, No. 1, Feb. 1955, pp. 107–119.
6. R. Gunn and C. Devin, Jr., "Raindrop Charge and Electric Field in Active Thunderstorms," *Journal of Meteorology*, vol. 10, No. 4, Aug. 1953, pp. 279–284.
7. L. B. Loeb, *Fundamental Processes of Electrical Discharge in Gases*, John Wiley & Sons, New York, 1939, 717 pp.

[*Received July 10, 1967; revised August 29, 1967*]